Reference Concentration for Shelf Sediment Transport Models

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LONG-TERM GOALS

The scientific focus of this project is to improve our understanding of near-bed suspended sediment concentration (i.e., "reference concentration") in the coastal environment. Models of sediment transport require parameterization of the reference concentration in terms of hydrodynamical and sedimentological measures. In this study we evaluate the accuracy and suitability of existing expressions for reference concentration based on field measurements, and develop an improved expression for this important parameter.

This work is undertaken as part of an ONR-sponsored Mine Burial Research Program. It is closely linked to the work of other investigators who are collaborating to understand oceanographic and seafloor processes that affect bottom mines. The principal goal of this research is to develop an expression for near- bed reference concentration in terms of readily measured hydrodynamic and sediment parameters. This expression is derived from high-quality field measurements in the shallow-water marine environment.

OBJECTIVES

- Evaluate existing formulations for reference concentration C_o and their applicability for sediment transport modeling.

- Obtain high-quality field measurements of important parameters that contribute to better understanding of C_o. These include detailed near-bed measurements of wave parameters, velocity profiles, suspended sediment concentrations and size distributions, bed morphology, and particle settling velocities.

- Determine relationships between bottom velocities and stresses in shallow-water marine environments and near-bottom suspended sediment concentrations C.

- Develop an accurate expression for C_o.

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14. ABSTRACT
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APPROACH

The latest numerical models that predict coastal sediment transport, erosion, and deposition require formulations of C and C_o that enable their computation from hydrodynamic (particularly bottom stress τ_b), sediment, and bed roughness parameters. Therefore, it is important to have reliable, accurate, and validated expressions that relate C and C_o to these other parameters.

This study investigates the performance of three commonly applied models for estimating C and C_o in the coastal zone. Model calculations of near-bed C are compared to direct estimates that were obtained from an Acoustic Backscatter System (ABS). The three models examined in this study are widely used, and are based on significantly different assumptions and theoretical formulations. The model of Nielsen (1986 and 1992) is entirely based on wave dynamics, and includes effects of vortex ripples on C and C_o. The other two models from Glenn and Grant (1987; hereafter GG87) and van Rijn and Walstra (2004; hereafter vRW04) incorporate the effects of both waves and currents on τ_b and C, and include effects of bedforms and a bed-load transport layer.

Our approach was to carry out a carefully designed field experiment to obtain data that are used to investigate C and C_o. The study site was seaward of the main pier in Santa Cruz harbor, Monterey Bay, CA, and was selected because of the likelihood for energetic wave conditions, the presence of a well-sorted sandy bed, and relatively simple logistics. Data that were collected included time-series wave measurements, near-bottom velocity profiles, suspended sediment concentrations and sizes close to the seabed, bottom sediment sizes, and bed roughness. This research is undertaken in collaboration with Dr. Yogi Agrawal, Sequoia Scientific Inc., and Dr. Peter Thorne, Proudman Oceanographic Laboratory, England.

WORK COMPLETED

Two instrumented bottom tripods were deployed off the public pier at Santa Cruz, California, in Monterey Bay during 4 – 19 March 2003. The tripods were equipped with some of the latest instruments for collecting data on waves, currents, C profiles, suspended sediment sizes, and small-scale bottom features (Thorne, et al, in press). The various sensors, measurement parameters, and sampling scheme for instruments used in this analysis are summarized in Table 1. The main objective was to compare model predictions of near-bottom C with reliable, accurate measurements of C in the nearshore zone. The ABS, Acoustic Current Profiler (ACP) and bottom imaging sonars were mounted on a bottom tripod that was designed for this study (Cacchione, 2005).

The tripods were deployed about 10 m from the end of the pier using a large mobile crane truck. The initial deployment took place at about 1400 PST 4 March 2003, and final recovery occurred about 1300 PST 19 March 2003. The ACP and bed sonars were hard-wired to a small mobile laboratory established inside of a van that was maintained on the pier terminus for the duration of the experiment. This uplink enabled real-time evaluation of ACP data quality, and selective sampling and recording of the sonar imagery. The sonar images were viewed real-time in the laboratory van, and selected for recording based on observed changes to the seabed morphology. Grain size distributions of bottom sediment showed that at the beginning of the experiment the sediment was moderately well-sorted with D_{50} (median) = 0.020 cm. At the end of the 15-day experiment, sorting of bottom sediment had improved, and D_{50} (median) coarsened slightly to 0.025 cm.

Table 1. Instruments and Sampling Scheme (for tripod used in this analysis).

Parameter	Instrument	Sampling Scheme
Velocity	ACP. 3 velocity components in 10 cm vertical bins from bed to 1.2 m ab	2048 samples at 2 Hz every 0.5 hr
Waves	Pressure transducer in ACP	2048 samples at 2 Hz every 0.5 hr
Particle size and concentration	ABS. 0.7 MHz, 2.0 MHz, 4.0 MHz in 2 cm vertical bins from bed to 1.28 cm ab	5248 samples at 4 Hz for each frequency every 0.5 hr
Bottom morphology	Sector-scanning sonar (SSS) Line-Scan Sonar (LSS, did not operate)	Images recorded as required

RESULTS

Some of the data that were collected with the tripod instrumentation were shown and described in last year's annual report for this project (Cacchione, 2005). Data collected on the second tripod with laser optical instrumentation were described by Thorne, et al (2006). This study used data from the tripod with instrumentation listed in Table 1. We were fortunate to capture the effects of a moderate storm that passed through the region on 14-16 March 2003. The storm was a typical late winter event for this area characterized by southerly winds of 20-30 knots that persisted for about 2 days. The measurements indicate that the hourly-averaged currents (non-tidal) reached about 40 cm/s at 1 m above the bed during the storm. Local significant wave heights (Hs) were about 1.5 – 2.0 m; peak spectral wave periods (Tp) were about 10-14 s. Maximum bottom wave velocities (Ub) were about 80 – 90 cm/s. Easily discernible changes to bed morphology were observed in the sonar records. These data were descibed in the previous annual report (Cacchione, 2005).

Non-cohesive bottom sediment like the sand in the study area is resuspended when τ_b ($\tau_b = \rho u_{b*}^2$) exceeds a critical threshold value τ_{cr}. The threshold conditions for transport are commonly defined in terms of a critical Shields parameter θ_{cr} that can be obtained from Shields curve or calculated from an equation fitted to the Shields curve (Soulsby, 1997). Hourly values of Shields parameter θ_b were calculated from hourly bottom shear velocity u_{*b} (Wiberg et al, 1994). These parameters are plotted in Figure 1 along with estimates of C at 1 cm above bottom (C_{a1}) obtained from the ABS data.

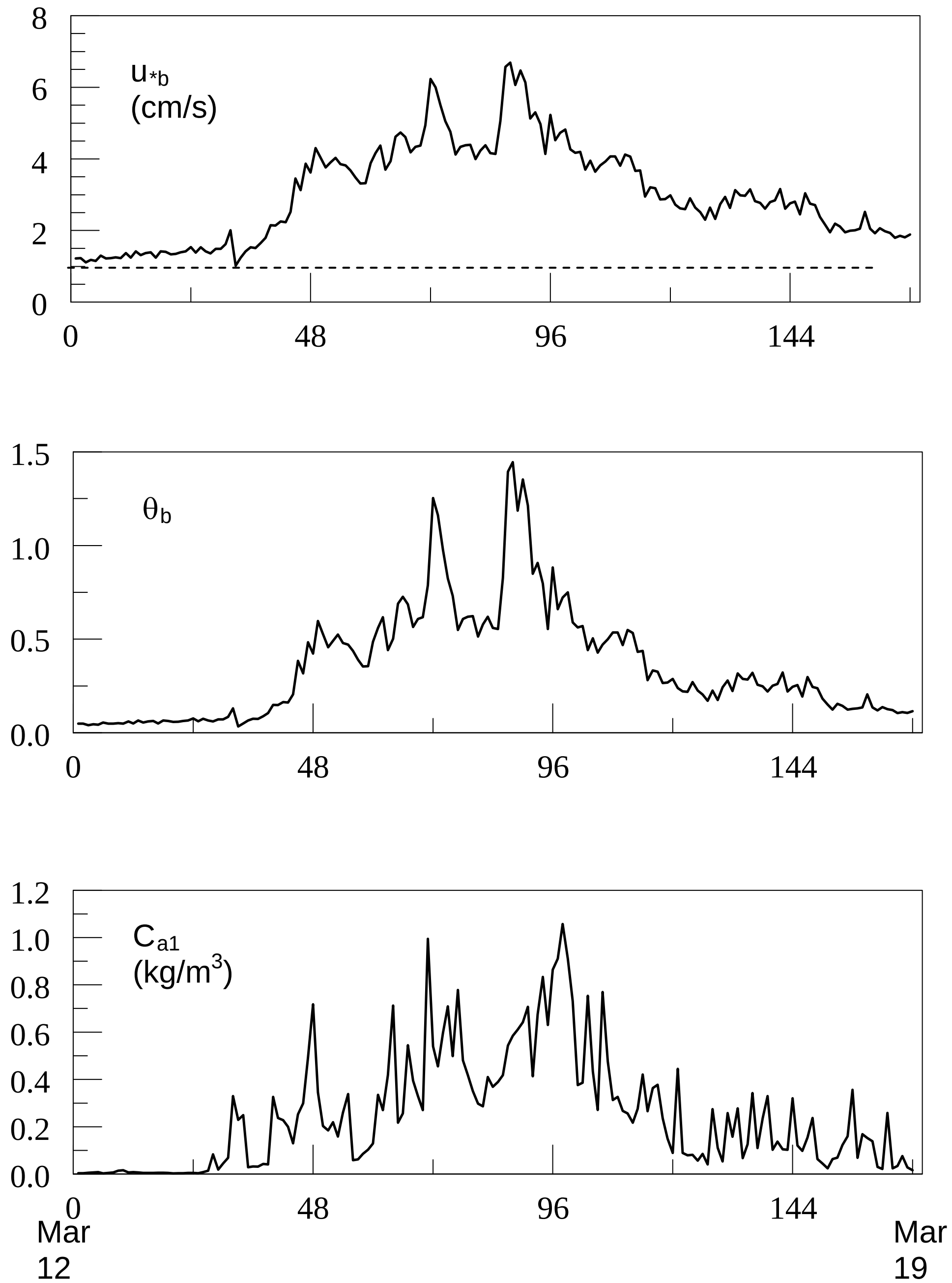

Fig. 1. ***u_{*b} is maximum bed shear velocity calculated from hourly burst ADP data using a wave-current bottom boundary layer model (Wiberg, et al, 1994). Dashed line indicates threshold shear velocity u_{*cr} = 1.3 cm/s for median sediment size D_{50} = 0.02 cm. Shields parameter θ_b was calculated from Soulsby (1997). C_{a1} is hourly burst-averaged suspended sediment concentration at 1 cm above bottom (ab) determined from ABS data.***

Based on the measurements and analysis to date we have found the following results.

Near-bed C calculated from three different models were compared with C_{a1} determined from field measurements using an ABS. The comparison was made at 1 cm ab. Mean C at 1 cm ab from all of the models was within 30% of mean C_{a1} (mean C from vRW04 was within 20%). This result is considered to be quite good considering the complexities in calculating sediment transport parameters such as near-bed C in natural environments. However, differences between hourly model results with C_{a1} were not as encouraging.

Differences between C_{a1} and Nielsen's model were at times rather large, particularly during periods of high bottom stresses. These differences are attributed to strong bottom currents during the storm that reached 40 cm/s. Contributions to bottom stresses from currents are not included in Nielsen's wave-driven model for C_o and near-bed C. In addition, ripple scales were over-predicted by Nielsen's bedform model. Ripple heights and wave lengths observed in sonar images of the seabed were much smaller than those calculated from Nielsen's ripple scale equations. The larger predicted ripple heights and wave lengths accounted for some of the differences in the hourly results. Nielsen's model compared well with C_{a1} toward the end of the experiment after the storm, when bottom currents were weak and ripple scales were small and in agreement with sonar bedform observations.

Estimates of near-bed C from Glenn and Grant (1987) appeared to track hourly C_{a1} quite well during the early part of the experiment until midway during the storm. After that the model consistently produced higher concentrations than C_{a1}. The onset of larger mega-ripples (with 3-D ripple geometry) combined with possible stratification effects that were unaccounted for in the model calculations might have caused these increased differences during the latter part of the record.

Good agreement between near-bed C calculated from the Delft method (van Rijn and Walstra, 2004) and C_{a1} was found throughout the experimental period except during the latter part of the record when storm-induced bottom stresses had decreased below threshold for the median sediment size. Calculations of u_{*b} using the Delft model produced values that were about 15-20% lower than those calculated from Wiberg, et al (1994). Lower u_{*b} during the last day of the experiment reduced model estimates of C_o and C, leading to consistently lower values in comparison with C_{a1}. This method and that from Glenn and Grant (1987) performed reasonably well despite the complexities in the resuspension process that included changing bed morphology and variable bed stresses due to waves and currents in the coastal waters of Monterey Bay.

IMPACT/APPLICATIONS

The results from our experiments will make important contributions to ongoing modeling efforts in sediment transport research. We have obtained an excellent data set to investigate the formulation of near-bottom suspended sediment concentrations. Most sediment transport models that have been developed for shallow ocean conditions require specification of the relationships between bottom stresses or shears to concentrations of suspended sediment near the bed. The existing formulations have not been tested and validated under combined wave-current flow conditions above a rough bed. This work will improve this aspect of our understanding and improve modeling of sediment transport.

TRANSITIONS

This work is part of the larger ONR Mine Burial Program efforts. It will be directly integrated into the overall understanding of how bottom mines react to physical processes in shallow water, including scour around mines, mine burial, and mine reorientation and movement. This work will also improve the accuracy of numerical sediment transport models.

RELATED PROJECTS

Collaborative projects are: (1) P.D. Thorne -- Utilization of acoustics for monitoring local and nearfield mine burial processes: Proof-of-concept; ONR Award Number: N00014-01-1-0549; and (2) Y. Agrawal -- Reference Concentration for Shelf Sediment Transport Models; ONR Award Number: N0001499C0448.

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